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(54) A method for using residue gas in gas turbines

(57) A residue gas from source 26 is heated prior to dispersal to atmosphere by introducing it as a separate cooling stream into the dilution zone 24 of a gas turbine combustor 14, the cooled mixture being expanded through turbine 10 driving air compressor 12. The residue gas may be compressed by an additional compressor 30 and some of the gas may be added to the turbine exhaust at 52.

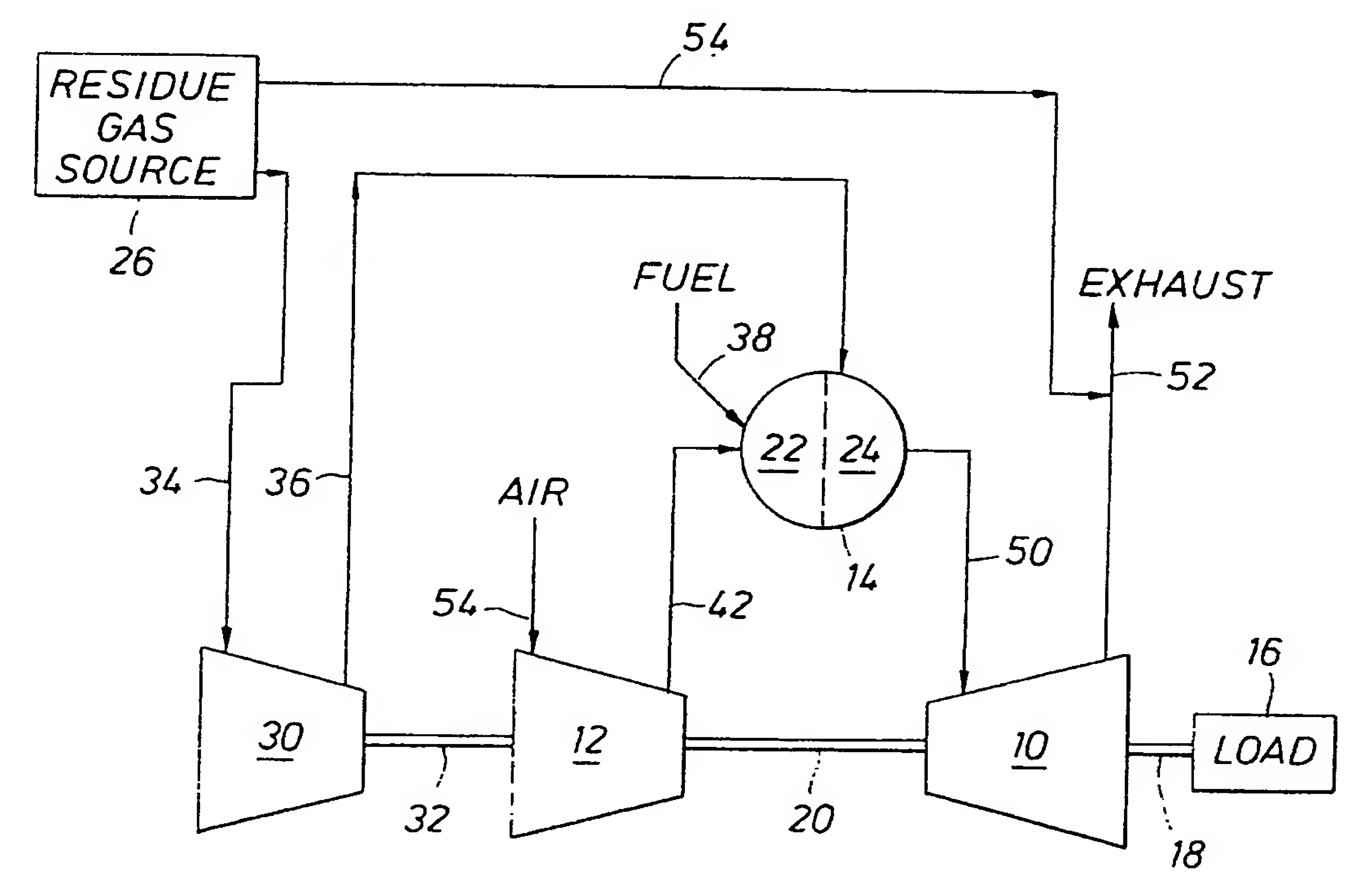

FIG. 2

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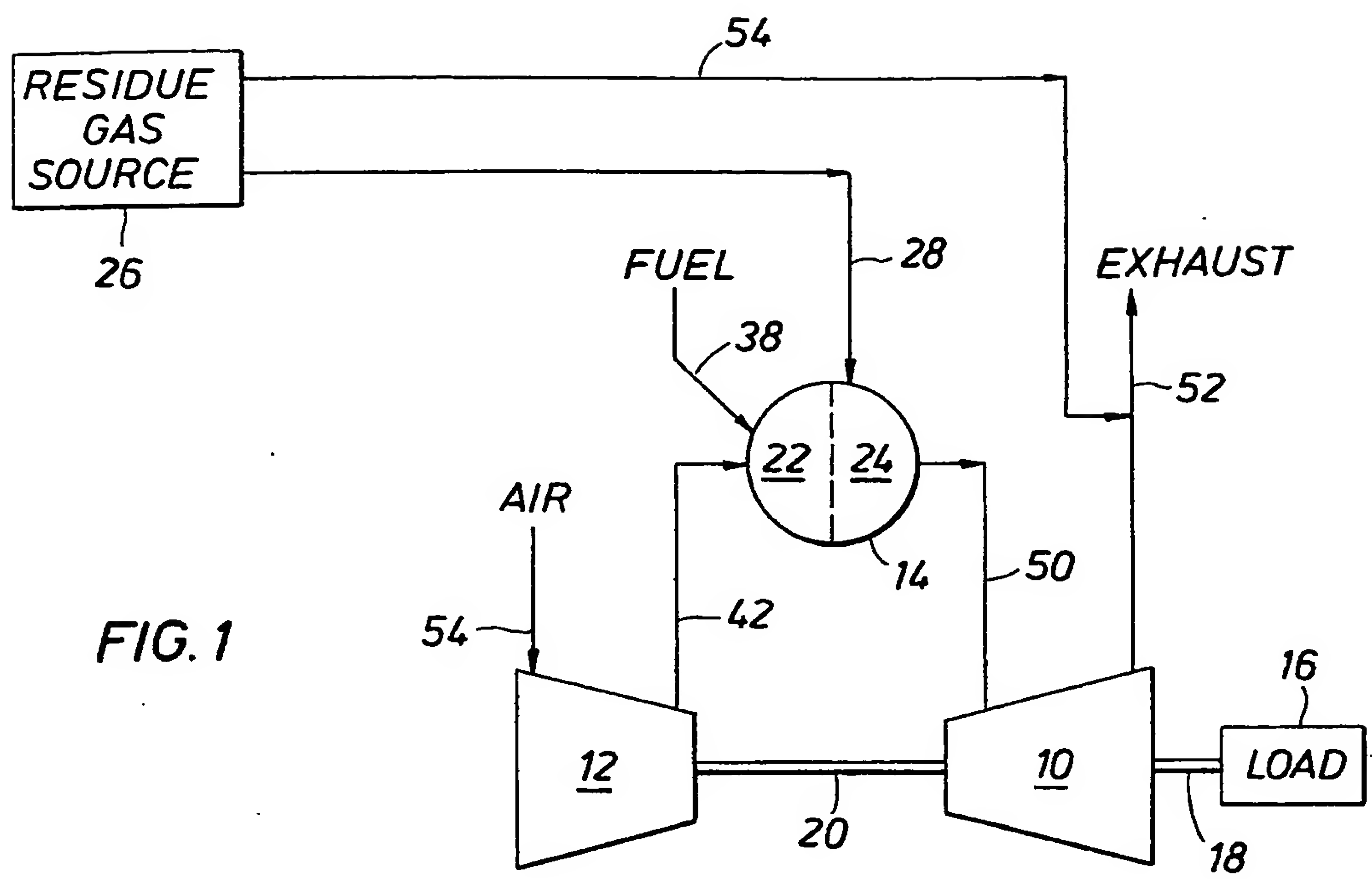

FIG. 1

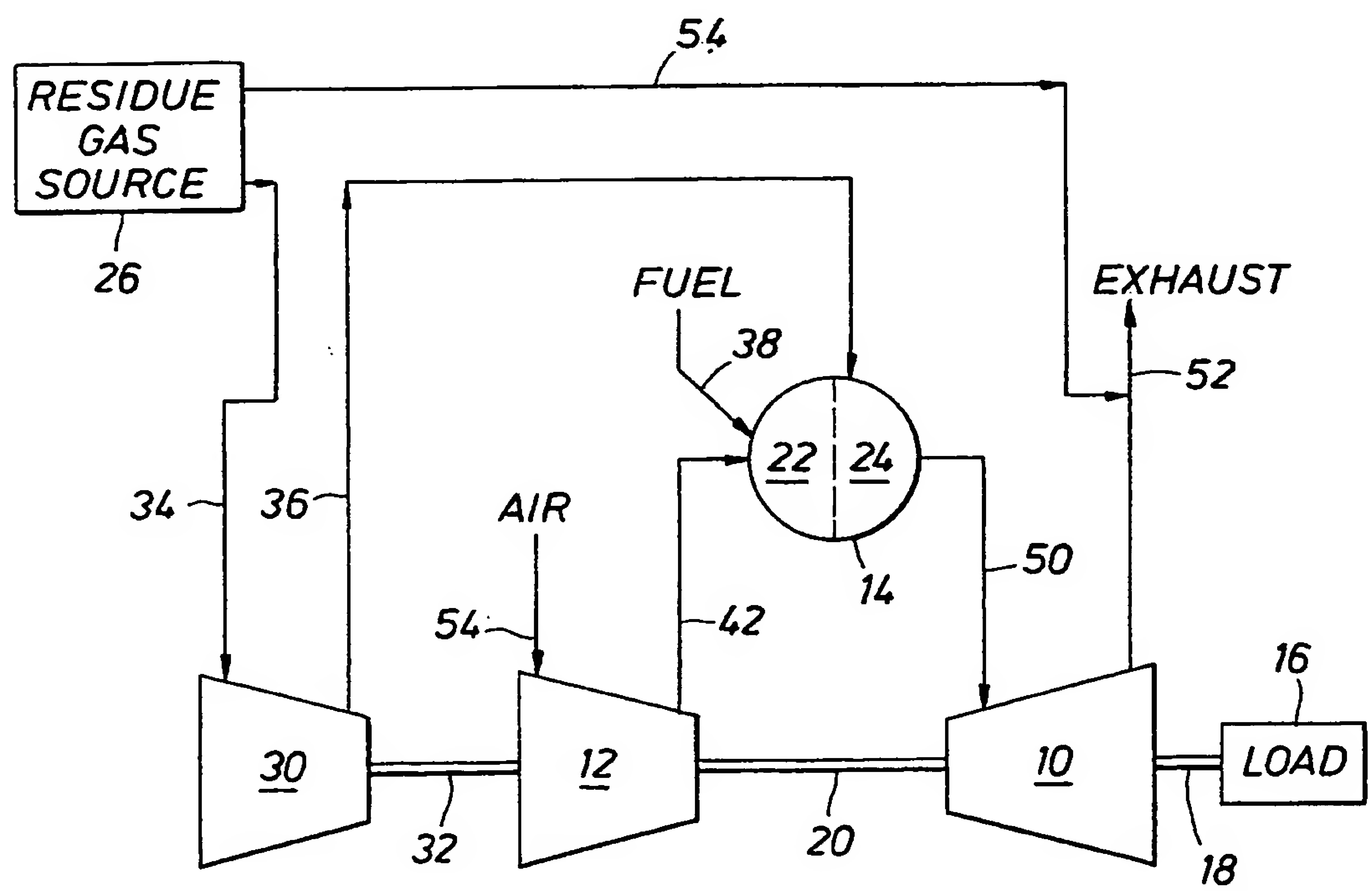

FIG. 2

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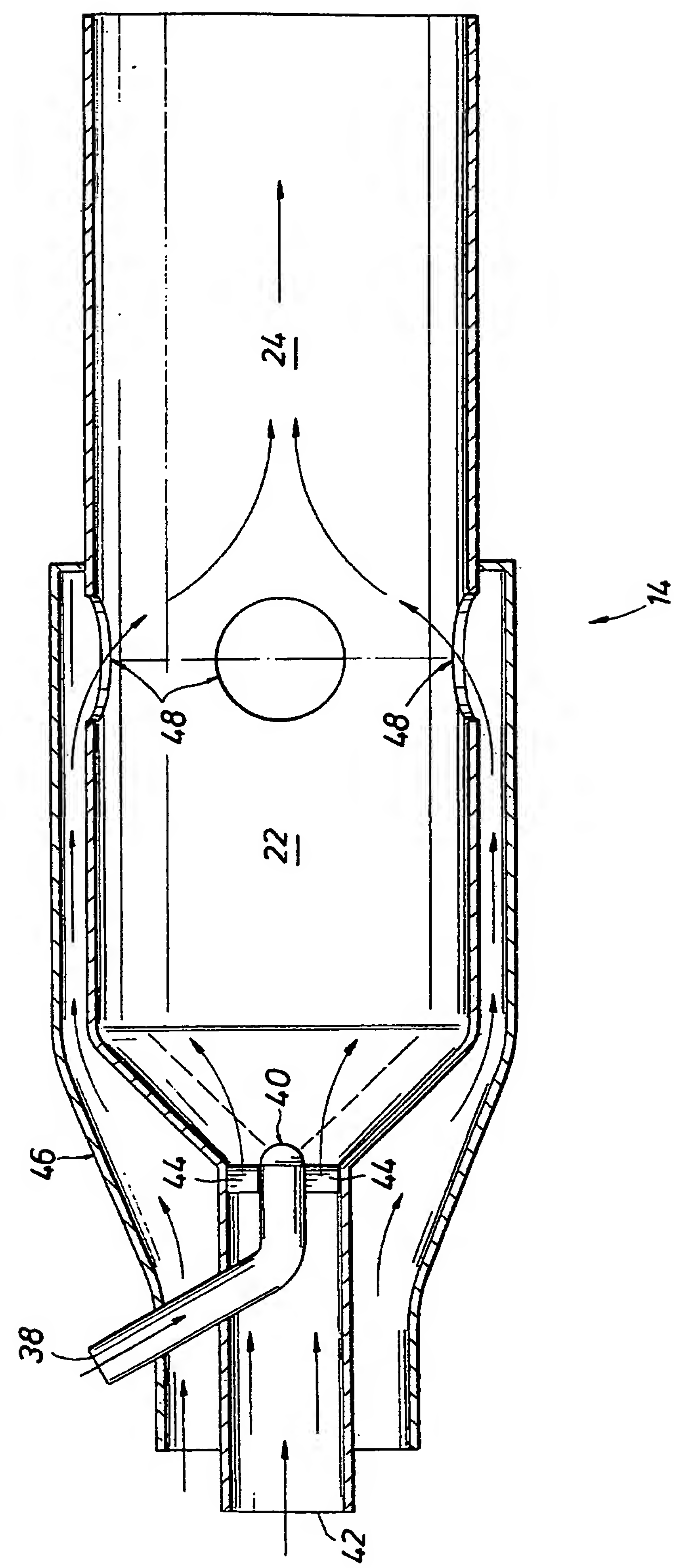
FIG. 3



SPECIFICATION

A method and apparatus for using residue gas in gas turbines

This invention relates to a method and apparatus for use in the disposal of residue gas and to improvements in gas turbines. In particular, the invention pertains to the use of a residue gas as a separate cooling stream in a gas turbine combustor whereby the overall efficiency of the gas turbine may be increased and the residue gas is heated so as to facilitate its dispersal to the atmosphere.

Oil and gas treating facilities, refineries and other industrial operations often produce large quantities of residue gas having little or no value. The residue gas may be naturally occurring, as for example the carbon dioxide (CO_2) which is often produced along with natural gas from a natural gas well, or it may be a by-product of an industrial operation. Regardless of source or kind, these residue gases must be disposed of. Frequently, the only practical method for disposal is to discharge the residue gases to the atmosphere.

Any such discharge to the atmosphere must, of course, comply with all applicable environmental regulations. For example, the discharge of residue gases such as carbon monoxide (CO) or hydrogen sulfide (H_2S) is strictly regulated. However, in addition to the obvious environmental concerns, the discharge of large quantities of residue gas, even if environmentally unobjectionable, may be hazardous to persons in the immediate vicinity of the discharge. If the density of the residue gas being discharged is greater than that of the surrounding air the residue gas will displace the lighter air settling in a blanket in the area of the discharge. This creates a hazard of asphyxiation to persons in the area. An example of this is the discharge of large quantities of CO_2. Discharge of CO_2 is normally environmentally unobjectionable. However, due to the fact that CO_2 is denser than air, discharge of large quantities of CO_2 is potentially hazardous to persons in the area of the discharge.

The hazard described above may be reduced or eliminated by heating the residue gas prior to discharge. If the temperature of the gas is raised to the point where its density is less than that of the surrounding air, the gas will rise upon discharge and disperse in the surrounding air rather than settling in a blanket at the point of discharge. Thus, by preheating the residue gas large quantities can be safely discharged.

Unfortunately, the above solution to the disposal problem is economically undesirable. Direct heating of the residue gas consumes large quantities of energy and, consequently, disposal costs are high. There is, therefore, a need for a more economical method of disposing of large quantities of residue gas.

One method which has been proposed for solution of this problem is to mix the residue gas with the exhaust stream of a gas turbine. Gas turbines are frequently used at industrial sites for operations requiring a source of rotary power, as for example the generation of electricity. Gas turbines are used extensively in the oil and gas industry. At refineries they are used as drive units for compressors and pumps and at oil and gas wells they are used for pressure maintenance. Typically, the temperature of the exhaust gases of an industrial gas turbine is in the range of 500—1000°F. Thus, introducing the residue gas to be disposed of into the exhaust stream of a gas turbine can help to solve the disposal problem. This solution, while providing some relief, is frequently inadequate to dispose of all available residue gas.

Briefly, the present invention deals with the disposal problem by using the residue gas as a separate cooling stream in a gas turbine combustor. This greatly increases the amount of residue gas which can be safely disposed of by a gas turbine and, additionally, may result in an increase in the overall efficiency of the gas turbine.

Gas turbine combustors consist of one or more separate combustion chambers, known as combustion cans. These combustion cans typically have two principal zones, a combustion zone where fuel is mixed with compressed air and burned and a dilution or cooling zone where the hot combustion products are mixed with additional compressed air so as to reduce the temperature of the combustion products to a temperature which will not be harmful to the turbine. Typically, only about 1/3 to 1/4 of the compressed air delivered by the turbine's compressor is used for combustion with the remainder being used for cooling the hot combustion products.

Pursuant to the present invention, the compressed air used in the dilution zone of the combustion cans for cooling the hot products of combustion is replaced with compressed residue gas. Thus, the amount of air which must be compressed by the turbine's compressor is reduced. Often, the residue gas is available at a pressure equal to or greater than the pressure of the combustion products in the combustor. In this situation the residue gas may be introduced directly into the dilution zone of the combustor and the reduction in the amount of compressed air which must be supplied by the compressor may result in an increase in the overall efficiency of the gas turbine. If only low pressure residue gas is available, the beneficial effects of reducing the amount of compressed air required may be equaled or exceeded by the necessity of compressing the residue gas. In either case, additional residue gas may be added to the exhaust stream of the gas turbine so as to increase the total amount disposed of.

The invention is described with reference to the drawings wherein

Figure 1 is a flow diagram of the gas turbine system of the present invention;

Figure 2 is a modified flow diagram of the gas turbine system of the present invention showing the use of a secondary compressor to pressurize low pressure residue gas; and

Figure 3 is a cross-sectional side view of a typical gas turbine combustion cam modified in accordance with the present invention.

Figure 1 diagrammatically illustrates the use of the gas turbine system of the present invention for disposing of high pressure residue gas. Figure 2 illustrates the use of the invention to dispose of low pressure residue gas. Referring now to Figures 1 and 2, the gas turbine of the present invention consists essentially of turbine 10, air compressor 12, and modified combustor 14. The gas turbine is used to drive load 16 which may be anything requiring a rotary power source. For example, load 16 may be an electrical generator, a pump or a compressor. Turbine 10 is mechanically connected to load 16 by drive shaft 18 which may include additional intermediate power transmission equipment such as gears, speed reducers, clutches, transmissions or the like (not shown). Turbine 10 and compressor 12 are mechanically connected by compressor drive shaft 20. As with drive shaft 18, compressor drive shaft 20 may include additional intermediate power transmission equipment (not shown). Both drive shaft 18 and compressor drive shaft 20 are powered by turbine 10.

Gas turbine combustors vary widely in design and arrangement. For detailed information on combustor design see *Sawyer's Gas Turbine Engineering Handbook*, Second Edition, Gas Turbine Publications, Inc., 1976; see especially Chapter 7 entitled "Combustor Design" by Herbert R. Hazard, Volume 1 at pp. 151—167.

Gas turbine combustors consist of one or more separate combustion chambers which will be hereafter referred to as combustion cans. Each combustion can consists of a primary zone where fuel is burned and a dilution zone where the products of combustion are cooled. The combustor may be totally independent of the turbine and its associated air compressor, or, alternatively, may be integral with the turbine and the air compressor. Typically, a gas turbine combustor consists of several combustion cans arranged to form an annulus around the drive shaft connecting the turbine and the air compressor.

Regardless of type or arrangement, all combustors perform the same basic functions. Fuel is injected by an atomizing nozzle into the primary zone of the combustion can where it is mixed with compressed air supplied by the turbine's compressor and ignited. The hot combustion products are then mixed with additional compressed air in a secondary dilution zone of the combustion can. The purpose of this dilution is to cool the combustion products to a temperature suitable for use in the turbine and to cool the combustion can itself. Normally only about 1/3 to 1/4 of the compressed air delivered by the turbine's compressor is used for combustion. The remaining 2/3 to 3/4 of the compressed air is used for dilution and for cooling.

Pursuant to the present invention, the compressed air used for dilution and cooling is replaced with pressurized residue gas. Referring again to Figures 1 and 2, modified combustor 14 is shown schematically. As stated above, modified combustor 14 would typically consist of several individual combustion cans arranged to form an annulus around compressor drive shaft 20; however, for simplicity it will be assumed that modified combustor 14 consists of only one combustion can. The dashed line indicates the transition between combustion zone 22 and dilution zone 24.

The residue gas source 26 (shown in block form) may be any source which produces large quantities of residue gas. The temperature of the residue gas at the residue gas source 26 would typically be less than or equal to ambient. Referring now to Figure 1, it is assumed that the residue gas is available at a pressure equal to or greater than the pressure of the products of combustion in modified combustor 14. For example, CO_2 may be produced as a residue gas from natural gas treating facilities at very high pressures. In this situation, the residue gas flows directly from residue gas source 26 to the dilution zone 24 of modified combustor 14 via pipeline 28. Pipeline 28 may include additional pressure and/or flow regulation equipment (not shown). If, on the other hand, the residue gas is available only at a low pressure it must be pressurized before entering modified combustor 14. As shown in Figure 2, this pressurization is accomplished by secondary compressor 30 will be compressor 30 may be driven independently of turbine 10. Alternatively, as shown in Figure 2, secondary compressor 30 may be mechanically connected to compressor 12 by secondary compressor drive shaft 32. In this case the input power for driving secondary compressor 30 is produced by turbine 10 and transmitted to secondary compressor 30 by compressor drive shaft 20, compressor 12, and secondary compressor drive shaft 32. Other methods of powering seconary compressor 30 will be readily apparent to those skilled in the art. The residue gas is fed from residue gas source 26 to the inlet of secondary compressor 30 by pipeline 34. After compression the residue gas flows from secondary compressor 30 to the dilution zone 24 of modified combustor 14 via pipeline 36 which may include additional pressure and/or flow regulation equipment (not shown).

Figure 3 illustrates one method of designing modified combustor 14. Fuel enters modified combustor 14 through fuel pipeline 38 and is sprayed into combustion zone 22 by atomizing nozzle 40. Air enters compressor 12 through air intake 54. After being compressed the air is fed into the combustion zone 22 by compressed air pipeline 42. The compressed air enters the combustion zone through swirl vanes 44 which surround fuel pipeline 38. The purpose of these swirl vanes, which are well known to persons skilled in the art, is to create a turbulent flow pattern thereby enhancing the

mixing of the fuel and the compressed air. This mixing promotes complete combustion. Pressurized residue gas delivered by pipeline 28 (Figure 1) or by pipeline 36 (Figure 2) flows through jacket 46 which surrounds combustion zone 22. The residue gas enters the interior of the combustor through ports 48. The number of ports necessary is dependent on several factors such as flow rate, pressure and temperature. The hot combustion products and the residue gas are mixed in the dilution zone 24. This mixing produces the working fluid which will be used to power the turbine. Other methods of modifying existing combustors or of designing new combustors for use in accordance with this invention will be readily apparent to those skilled in the art of combustor design.

After combustion and dilution the working fluid leaves modified combustor 14 and flows through pipeline 50 to the inlet of turbine 10. After performing work on the turbine, the spent working fluid is exhausted to the atmosphere through exhaust pipe 52. Additional residue gas may be added to the exhaust pipe by pipeline 54.

In practising the method of the present invention, the compressed air normally used for cooling in the dilution zone of a gas turbine combustor is replaced with pressurized residue gas. This results in a corresponding reduction in the amount of air which must be compressed by the turbine's air compressor. If, as is often the case, the residue gas is available at a high pressure, the reduction in the amount of air which must be compressed will result in increasing the overall efficiency of the turbine.

The gas turbine combustor 14 must be modified so as to accept the pressurized residue gas as a separate cooling stream for use in the dilution zone 24. This cooling stream must be kept separate from the pressurized air used for combustion in the combustion zone 22. One method of modifying a typical gas turbine combustor in accordance with the present invention is illustrated in Figure 3. Other methods of modifying gas turbine combustors for use in practising the present invention will be readily apparent to those skilled in the art.

If the residue gas is available at a sufficiently high pressure for use in modified combustor 14, as illustrated in Figure 1, it may be fed directly into the dilution zone 24 of modified combustor 14. If, on the other hand, only low pressure residue gas is available, as illustrated in Figure 2, secondary compressor 30 must be used to pressurize the residue gas prior to its use in modified combustor 14. In either case, additional residue gas may be added to the gas turbine's exhaust stream 52 so as to increase the total amount disposed of.

Example

A computer study was conducted in order to compare the operating characteristics of a standard gas turbine engine (Case 1) with those of a gas turbine engine modified in accordance with the present invention (Case 2). The particulars of the computer programme used are not presented herein. However, the programme was based on standard principles of thermodynamics which are well known to those skilled in the art. The results presented herein could be easily duplicated by such persons, with or without the aid of a computer.

In both cases, the gas turbine engine was assumed to have a nominal horsepower of 5000. Fuel flow rate was set at 5000 pound mol/day. Fuel pressure was assumed to be 800 psia and fuel temperature was set at 40°F. The composition of the fuel gas used was as follows:

Component	*mol %*
Carbon Dioxide	19.98
Methane	77.05
Ethane	1.17
Propane	0.26
n-Butane	0.07
Nitrogen	1.47
	100.00

In order to determine the amount of air necessary for burning, it was assumed that all combustible components of the fuel gas would be completely converted to either carbon dioxide (CO_2) or water (H_2O). Based on this assumption, a stoichiometric balance was used to determine the amount of oxygen (O_2) necessary to completely convert all combustible material. That calculation indicated that 39,650 pound mol of air is necessary to provide sufficient oxygen to totally combust 5000 pound mol of the above fuel gas.

Complete combustion of 5000 pound mol/day of the above fuel gas will provide a total heat input to the gas turbine engine of 57,690,000 BTU/hour. Thus, if the gas turbine engine operated at a thermal efficiency of 100%, the power output would be 22,668 horsepower.

Typically, the amount of compressed air that is used in a gas turbine combustor for dilution and cooling is 2 to 3 times greater than the amount necessary for complete combustion. In case 1 it was assumed that the amount of dilution air was 2-1/2 times larger than the amount of combustion air. Thus, the total compressed air used in Case 1 was 3.5 times the 39,650 pound mol/day required for

combustion alone or 138,775 pound mol/day. This air was assumed to be available at a pressure of 14 psia and a temperature of 90°F before being compressed to an operating pressure of 80 psia. Additionally, the air was assumed to be 100% saturated.

In Case 2 the residue gas was assumed to be carbon dioxide (CO_2). The CO_2 was assumed to be available at a pressure of 53 psia and a temperature of −5°F, and was further compressed to a pressure of 80.5 psia for use in the modified combustor. The composition of the CO_2 was assumed to be as follows:

Component	*mole %*
Carbon Dioxide	98.74
Methane	0.89
Ethane	0.09
Propane	0.10
n-Butane	0.17
Water	0.01
	100.00

The above characteristics are typical of the CO_2 streams which are often produced as residue at natural gas treating facilities.

In order to ensure complete combustion, Case 2 assumed that 50% excess compressed air was used. Thus, the total compressed air used was 59,475 pound mol/day. As with Case 1, this air was assumed to be 100% saturated. The remainder of the compressed air used in Case 1 was replaced with 40,000 pound mol/day of CO_2.

The following is a comparison of the operating characteristics of the two systems:

	Case 1	*Case 2*
Turbine Inlet Temperature (°F)	1,549	1,521
Turbine Outlet Temperature (°F)	966	1,030
Turbine Horsepower Obtained (b.h.p.)	11,100	8,158
Compression Horsepower Required		
Air (b.h.p.)	6,990	2,996
CO_2 (b.h.p.)	—	315
Total	6,990	3,311
Net Horsepower (b.h.p.)	4,110	4,847
Thermal Efficiency (%)	18.13	21.38

In both cases, compressor and expander efficiencies were assumed to be 80% and 85% respectively. The turbine outlet temperature for each case was determined by comparing the enthalpy of the exhaust stream to the enthalpy of the combined inlet streams (compressed air, CO_2 and fuel). The outlet temperature was varied until the difference between the above enthalpies was exactly equal to the fuel flow rate times the fuel's net heating value.

In the above example, 40,000 pound mol/day of compressed CO_2 was used to replace 79,300 pound mol/day of compressed air. As evidenced by the difference in the turbine inlet temperatures, the smaller amount of CO_2 provides better cooling than the larger amount of air.

In Case 2 the total mass flow rate through the turbine is 39,300 pound mol/day less than the mass flow rate in Case 1. This reduction in mass flow rate is the basic cause for the reduction in turbine horsepower obtained from Case 1 to Case 2. More importantly, however, even though total horsepower obtained decreased from Case 1 to Case 2, the net horsepower available for work is considerably greater in Case 2 than in Case 1. This is due to the substantial reduction in the amount of horsepower required for compression. Additionally, the overall thermal efficiency in Case 2 is better than in Case 1.

In Case 2 the CO_2 was assumed to be available at 53 psia and was further compressed to 80.5 psia. This compression required 315 horsepower. If the CO_2 were available at a pressure above 80.5 psia, this 315 horsepower would not be needed, resulting in a further increase in net horsepower available and thermal efficiency. Conversely, if the CO_2 is available only at low pressure, more than 315 horsepower would be necessary for compression. This could negate some or all of the increases in horsepower and thermal efficiency.

In addition to the primary benefit of disposing of large amounts of CO_2, an added benefit of the invention is that when CO_2 is used for dilution a reduced mass flow rate will result in equal or more net horsepower being generated. Since mass flow rate is one of the limiting factors in gas turbine design a smaller turbine may be used for a particular job.

The following is a comparison of the CO_2 dispersion capability for Case 1 and Case 2. For

purposes of this comparison, an exhaust gases flow rate of 100,000 pound mol/day was assumed for both cases.

	Case 1	*Case 2*
Temperature of Exhaust (°F)	966	1,030
Amount of CO_2 in Exhaust		
(%)	3.49	43.58
(pound mol/day)	3,490	43,580
Amount of CO_2 added to Exhaust at 100°F (pound mol/day)	142,000	183,000
Stack Temperature (°F)	407	417
Total Amount of CO_2 dispersed (pound mol/day)	145,490	226,580

In the above comparison it was assumed that a final stack temperature of at least 400°F was necessary in order to ensure proper dispersion in the atmosphere. In Case 1 the exhaust stream contains 3,490 lb mol/day of CO_2 which was produced in the combustion process. Additionally, 142,000 pound mol/day of CO_2 at a temperature of 100°F may be added to the exhaust stream resulting in a final exhaust stream temperature of 407°F. Thus, the total amount of CO_2 which may be dispersed by a standard gas turbine having a mass flow rate of 100,000 pound mol/day is 145,490 pound mol/day.

In Case 2 the exhaust stream contains 43,580 pound mol/day of CO_2, the majority of which was added for dilution purposes. Additionally, 183,000 pound mol/day of CO_2 at 100°F may be added to the exhaust stream resulting in an exhaust temperature of 417°F. The total amount of CO_2 dispersed by a gas turbine engine modified in accordance with the present invention and having a mass flow rate of 100,000 pound mol/day is 226,580 pound mol/day.

The method and apparatus of the invention and the best mode contemplated for applying that method have been described. It should be understood that the foregoing is illustrative only and that other means and obvious modifications can be employed without departing from the true scope of the invention defined in the following claims. For example, so long as the combustion air is kept separate from the residue gas, any combustor design may be used. Also, residue gases other than CO_2 may be used.

Claims

1. A method for using a gas turbine engine having an air compressor, a combustor, and a turbine to heat a residue gas prior to dispersing said residue gas in the atmosphere, which comprises

introducing said residue gas as a separate cooling stream into the dilution zone of said gas turbine combustor; and

dispersing said residue gas to the atmosphere.

2. A method for using the combustor of a gas turbine engine to heat a residue gas prior to discharging said residue gas to the atmosphere, said combustor having a combustion zone where fuel is mixed with compressed air and burned to form products of combustion and a dilution zone where the products of combustion are cooled to a temperature suitable for use in the turbine, which method comprises

introducing said residue gas as a separate cooling fluid into said dilution zone of said combustor, whereby heat is transferred from said products of combustion to said residue gas;

passing said heated residue gas and said products of combustion through said turbine whereby energy is transferred to said turbine; and

exhausting said heated residue gas and said products of combustion to the atmosphere.

3. A method according to either of claims 1 and 2 which comprises using a separate compressor to pressurize said residue gas prior to introducing said residue gas into said dilution zone of said combustor.

4. A method according to any one of the preceding claims which comprises introducing additional residue gas into the exhaust stream of said gas turbine engine.

5. A gas turbine engine for use in heating a residue gas prior to dispersing said residue gas in the atmosphere, said gas turbine engine comprising:

an air compressor;

a turbine; and

a combustor having a combustion zone where fuel is mixed with compressed air from said air compressor and burned and a dilution zone where the products of combustion are mixed with pressurized residue gas, whereby the products of combustion are cooled to a temperature suitable for use in said turbine and the residue gas is heated for dispersal to the atmosphere.

6. A gas turbine engine according to Claim 5, which comprises a second compressor for pressurizing said residue gas prior to introduction of said residue gas into the dilution zone of said combustor.

7. A gas turbine system for use in disposing of residue gas comprising:

a source of pressurized residue gas;

an air compressor having an inlet for admitting atmospheric air into said compressor and an outlet for emitting compressed air;

a combustor having at least one combustion can, said combustion can having a combustion zone where fuel is mixed with compressed air from said air compressor and burned to form products of combustion and a dilution zone where said products of combustion are mixed with pressurized residue gas from said pressurized residue gas source to form a working fluid, whereby said products of combustion are cooled and said pressurized residue gas is heated; and

a turbine having an inlet for admitting said working fluid and an outlet for exhausting said working fluid after said working fluid has performed work on said turbine.

8. A gas turbine system according to claim 7 wherein said source of pressurized residue gas is a compressor having an inlet for admitting low pressure residue gas and an outlet for emitting pressurized residue gas to said dilution zone of said combustor.

9. A gas turbine engine or system according to any one of claims 5 to 8 which comprises means for introducing additional residue gas into the exhaust stream of said turbine.

10. A gas turbine engine according to claim 5 substantially as hereinbefore described with reference to the drawings.

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